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A GEOREFERENCED INFORMATION SYSTEM FOR REAL TIME HYDROLOGIC MODELING

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I. ABSTRACT

Remotely sensed digital data (Landsat CCT) has proven an efficient and cost effective means of defining land cover information required in hydrologic modeling. However, an organization such as a county government finds great difficulty in collecting and integrating regional ancillary data (aerial photos,soils,etc) with digital remote sensed data.

A computer-based information system allowing engineers to create, access, integrate, and maintain a multi-parameter geographical data base which provides information required by the Soil Conservation Service hydrologic models is described. Land cover, soils, and elevation data are stored as arrays of cells referenced to USGS quad sheets.

A typical scenario involves the analysis of the impact of proposed land cover changes on the runoff hydrograph. In the interactive mode, the user inputs the location of an outfall cell. Enhanced picture processing algorithms applied to elevations determine the watershed area and stream network. The system routes the data contained within the watershed through the model for an input rainfall. The user recieves a peak discharge, statistics, and maps describing the watershed. Proposed changes are input to produce a present/proposed hydrologic comparison.

II. INTRODUCTION

One important aspect in the future planning of our world's community is the hydrologic effects of urbanization. In recent years numerous hydrologic models (SCS, EPA,HEC,etc) have been developed to predict these effects. These models have parameters dependent on the spatial distribution of land cover, soils, and topography. Research has shown that remotely sensed digital data (Landsat, Digital Terrain,etc) are an efficient and cost effective means of defining land cover and topography. However, regional jurisdicitions such as county governments ususally require ancillary modeling information derived from hard copy sources.

Therefore, there is a need for a methodology to collect, merge, and manage digital remotely sensed data and hard copy data into a regional data base. Secondly, a system must be developed to provide a user-oriented interface between the regional data base and hydrologic models. These concepts must be realised within the finite technical skills and computer level of the regional government.

A computer-based georeferenced information system known as the Hydrologic Analysis Program (HAP) allowing regional engineers and planners to create, access, intergrate, and maintain a multi-parameter geographic data base which provides information for hydrologic models is described. The major topics of HAP's data base management system, study area delineation, and the user-data base-hydrologic model interface will be presented.

III. LITERATURE

The concept of regional data bases is an accepted approach for supplying scientists with timely and accurate information. Developments in the major problems of data collection, data management, and user-data base interfacing has produced three distinct generations of regional data base systems. Istvan[1], Ragan[2], Fellows[3], Harding[4],Corps of Engineers[5], and Hardy[6] conducted research which produced many foundations of the regional data bases. These systems concentrated on methods of manual geoencoding and computer storage of spatial data.

In the late 1970's, the promise of digital satellite (Hessling[7]) and terrain data (Doyle[8] and Allam[9]) intiated additional research. Concurrently, advances in the new field of data base management systems were being made by pioneers such as Date[10] and Martin[11]. The marriage of these two disiplines produced what has been refered to as the georeferenced information system. Paul[12], Fellows[13], Adams[14], Strome[15], Whitley[16], Campbell[17], Kauth[18], Keller[19], and Shelton[20] contributed to what has become the standards of the georeferenced information system. These systems provided a great deal of flexability in the types of data they would accomendate and were user oriented. The concept of developing systems which could compose raw data into useful information, be utilized by non-technical users, and provide real-time answers was becoming a realty. Users were being given navigational aides to explore the data base. It was no longer necessary for the user to understand the physical computer data file structure. Natural english languages were also being developed to address the data base.

As the second generation of systems were developing, the science of digital image processing was making tremendous advances in picture processing. These disiplines shared the common problems of manipulating large quantities of data. Research in image processing by Rosenfeld[21], Sklonsky[22], Dyer[23], and Robinson[24] and human perceptions by Pentland[25] illustrated the impact picture processing principles could have on information systems. The preprocessing, enhancement, segmentation, and restoration algorithms in picture processing helped develop the image data base system. These image systems researched by Shapiro[26], Zobrist[27], Chang[28], Lien[29], Tanura[30], and Mckeown[31] are sophisticated blend of data collection technology, data base management, image processing, and remote sensing. These systems have made it possible to perform tasks thought only to be accomplished by human visual perception. These tasks include edge detection; adjacentness, connectedness, and surroundedness of objects; removing local and global anomalies; and matching shapes and textures. The third generation information system uses these image processing algorithms applied to the analogous land cover, soils, elevation, etc "picture" to further automate the user-system interface.

This study intends to develop a third generation georeferenced information system for urban planning and hydrologic modeling that encompasses all the multi-disiplinary concepts of data base management and image processing. However, these princples will be adopted for the use with regional governments of finite computational and technical resources. The addition of image processing algorithms will eliminate the subjective and inefficient watershed boundary and network delineation. Data collection, storage, and retrieval will be constructed to optimize the blending of digital data and hard copy data.

IV. HAP DEVELOPMENTAL DATA BASE

HAP was developed by the University of Maryland Civil Engineering Department for operational usage at the water resources/ planning offices of the Maryland National-Capital Park and Planning Commission (MN-CPPC). The MN-CPPC is responsible for the planning of the 400 square mile Montgomery County, Maryland which borders the northwest boundary of Washington D.C.. Grid encoded hydrologic soil groups from soil maps, topography from USGS quad sheets, urban land cover from aerial photography, and suburban/rural land cover from Landsat were supported by HAP for Montgomery County.

V. HAP MODEL

Figure 1 shows that HAP consists of a data base management system, boundary delineation and hydrologic analysis component. A typical scenario was developed by

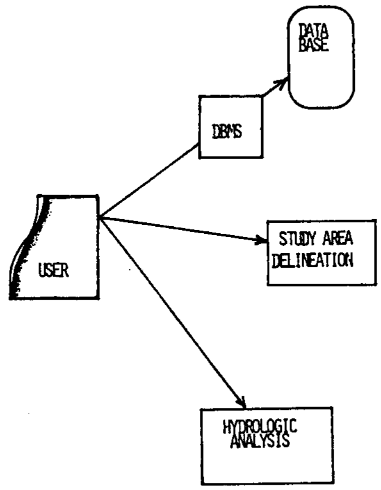


Figure 1. HAP MODEL

the MN-CPPC to ensure HAP would be constructed to satisfy their needs. The MN-CPPC required s system that could store and manage their land cover, soils, and slope data such that a contractor requesting a land development permit would supply the watershed boundary and proposed hydrologic changes. The system would route all necessary data through the hydrologic model for a given rainfall. The present/proposed hydrologic conditions would then be compared. This process would be real-time so the permit is issued or denied during the contractors initial visit.

A. DATA BASE MANAGEMENT SYSTEM (DBMS)

The objective of the HAP DBMS was to

provide a method for nontechnical personnel to create, load, access, and maintain spatial data differing in physical format. Information management princples of data independence and data models were incorporated.

Data independence is achieved by the DBMS provided information can be extracted from the data base without the knowledge of its physical storage. The user makes an english like data base request and the DBMS translates the request into the appropriate physical file manipulations. This concept allows users to write programs without concern of data formats. Data independence also provides the mechanism inwhich data of differing format (integer, alphabetic,etc) can be merged into one central data base.

Data independence is accomplished by providing the user with a data model and definition. Figure 2 illustrates the HAP data model/definition. These are navigat-

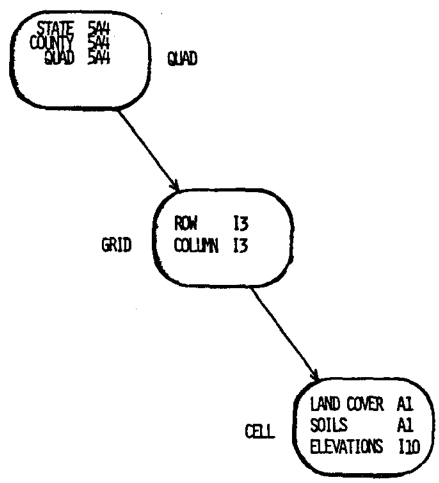


Figure 2. Data model and defintion.

ional aides to assist the user in data base requests. The QUAD-GRID-CELL data model shows the user the logical view of the data structure. Montgomery County, Maryland is comprised of nineteen USGS topo sheets (Figure 3). Each quad is subdivied into a N X M grid of cells. These cells contain the hydrologic information for the area. The MN-CPPC cell size usage was 4.58 acres. However, HAP will accomendate any cell size.

The data definition is used during the intial data base load to identify the type and size of the data fields. The loading sequence is dictated by the data model and definition. A STATE-COUNTY-QUAD name is loaded into HAP according to the Fortran field data definition. Iteratively, the row/column location of each cell is

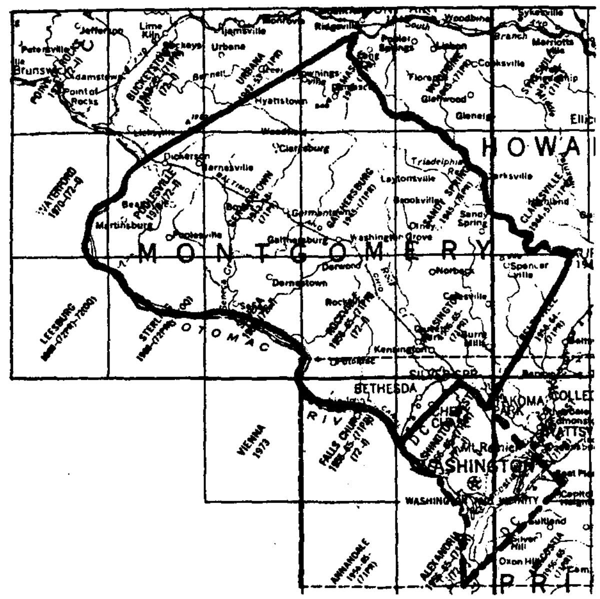


Figure 3. Montgomery County, Maryland.

is input along with the cell's spatial data until the grid is exhausted. The loading process produces a table of random access record address pointers for the topos loaded. These pointers will be used in data base queries to facilitate non-sequential searches through the data base.

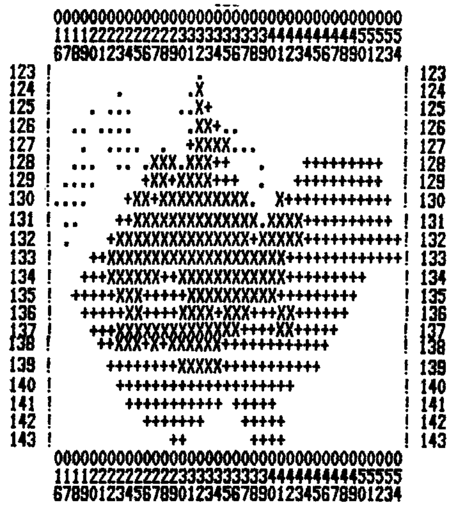
The optimal HAP query is a request for all the information available within an input boundary. In the near future, HAP will compose data types to produce new information. For example, qualifying a set of land cover and soil types that constitute a sludge disposal site criteria. HAP also maintains the integrity of the data base by supplying the user with interactive/ batch updateing routines.

B. BOUNDARY DELINEATION (BD)

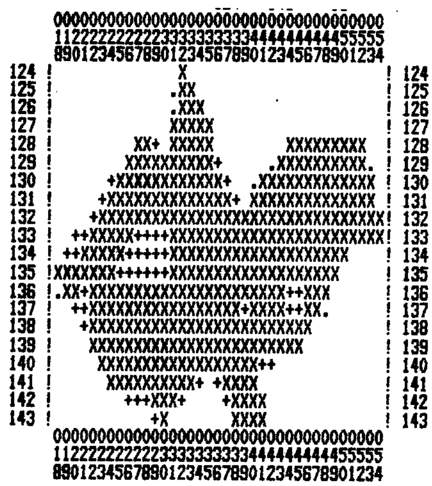
HAP provides an automatic delineation method for watershed boundaries and a manual grid/digitizer boundary input for political boundaries.

Automatic Delineation. Initially, watershed boundaries were required to be manually grid/digitized for input into HAP. However, this process was a burden to HAP's interactive format. Therefore, the watershed area and spatial distribution are determined by a modified picture processing algorithm known as "region growing" (RG). The user inputs the location of the outfall cell on the appropriate topo. the RG algorithm finds the cells of greater elevation that are hydrologically connected to the outfall cell. RG produces a binary (0,1) picture of cells. The "1" cells are counted and the cell's spatial information retrieved from the data base. Adjacent topos are retrieved from the data base as necessary.

During the development of the enhanced RG algorithm, it became clear that the process was very sensitive to erronous elevations. The RG algorithm was tested using USGS Digital Terrain Models (DEM) terrain tapes. This data proved to of questional quality (Stow[32]). Therefore, a noise-reducing preprocessing algorithm (Overton[33]) was designed to eliminate elevation anomalies.Figure 4 visually illustates the improvement in RG on preprocessed elevations.



(a)



(b)

Figure 4. (a) origional elevations. (b) preprocessed elevations. +=digital watershed, .=RG watershed, X=intersection

The stream network is determined by a "thinning" image processing algorithm. The edge of the (0,1) binary picture produced in RG is delineated by a laplacian operator:

$$\nabla^2 f(i,j) = |f(i-1,j-1)+f(i-1,j)+ f(i-1,j+1)+f(i,j+1)+ f(i+1,j+1)+f(i+1,j)+ f(i+1,j-1)+f(i,j-1)- 8*f(i,j)| \quad (1)$$

Where; the f(i,j)'s are the 8-cell neighborhood surrounding f(i,j) and i= j=1

The thinning or skeletonization algorithm eliminates any edge cell provided the elimination does not "disconnect" adjacent cells and the cell is a maximum local elevation. The resultant is the stream network. Figure 5 illustrates the thinning result of the Figure 4 watershed.

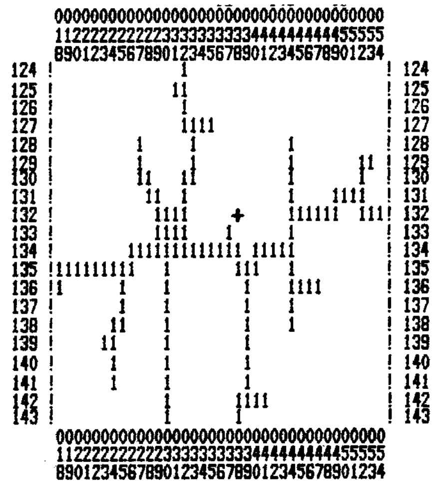


Figure 5. Thin of Figure 4. The + marks the location of the outfall cell.

Manual Delineation. Manual delineation may still be desirable in cases of bad data or political boundaries. HAP has both grid and electronic digitizer delineation. The watershed/political boundary is subdivided into polygons on the appropriate topos containing the study area. Once the sub-boundaries and appropriate topo pointers are input, the study area is masked together and the spatial information contained within the boundary retrieved from the data base.

C. HYDROLOGIC ANALYSIS

The hydrologic analysis module is the directive subroutine for HAP. The HAP DBMS and BD modules were designed to be called upon by the hydrologic analysis module.

The BD provides a method to identify a requested spatial area within the data base. The DBMS accepts this request and delievers the necessary information to the users computer program workspace. All information is passed via common statements. The MN-CPPC uses the SCS-TR-55 hydrologic model (SCS[34]). This model requires a cell-by-cell interface of land cover and soil to define a storage term (curve number), the watershed area, and slope to determine the peak discharge for a given rainfall intensity. A Fortran subroutine was written to inventory the spatial information delievered to the program workspace by the HAP DBMS request. HAP will accept any hydrologic model provided the model parameters can be defined by the information within the data base.

HAP has an UPDATE and MAP module. The UPDATE subroutine allows the user to input the location and proposed land cover, soil, or slope change for any cell(s) in the study area. The proposed conditions are routed through the model and a new peak discharge is produced. The MAP module can produce 1:48,000 and 1:24,000 gray scale maps of present/proposed study area conditions.

VI. TYPICAL HAP SESSION

The following computer output demostates a typical HAP interactive computer session. A private consulting firm in Maryland was requested to design storm water storage behind an existing conduit. HAP was used to determine the peak discharge for the present and proposed conditions for a 100 year 7.2 inch storm. The city's master plan was available to project the proposed land cover conditions. The location of the outfall cell on USGS topo was measured. The resulting HAP run Produced a 1:48,000 gray scale map of the RG watershed and a present SCS-TR-55 hydologic analysis. The proposed land cover changes were input. A proposed map and prsent/proposed hydrologic comparison were output. The users inputs are in lower case letters and the computer prompts/responses are in upper case letters.

```
UOM 1108 36.R2D:8
ACCOUNT NUMBER? @RUN BREWER,304621JACK,FELLOW,5,100

PASSWORD?
[redacted]

PRINT AND BACKLOG LOST 4/10 21:37
RUNID:  BREWER  04/14/81  01:14:35  LAST RUN: 04/14  01:14
DEMAND: 5, BATCH: 2, BACKLOG: 2

@asg,a debbie*base.
READY
@use 10.,debbie*base.
READY
@xqt debbie*hap.abs
 **********************HYDROLOGIC ANALYSIS PROGRAM*****************
 INPUT:
 B=BOUNDARY    H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
 U=UPDATE      S=STOP

b
 ===========================BOUNDARY MODULE=======================

 **INPUT BOUNDARY OR OUTFALL(B/O)?**
o
 **INPUT X/Y OF OUTFALL**
4.00
6.25
**INPUT STUDY TITLE**
land cover impact study
**INPUT TOPO NUMBER(REAL)**
1.
 ==============LAND COVER IMPACT STUDY        BOUNDARY COMPLETE====


 **********************HYDROLOGIC ANALYSIS PROGRAM*****************
 INPUT:
 B=BOUNDARY    H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
 U=UPDATE      S=STOP

h
 ==========================SCS MODEL MODULE========================

 **INPUT RAINFALL IN INCHES(REAL NUMBER)**
7.2

         ===WATERSHED ANALYSIS (SCS-TR-55)===

 IDENTIFICATION=LAND COVER IMPACT STUDY

 WEIGHTED CURVE NUMBER=     71.17
 AVE PERCENT SLOPE=     5.34
 AREA=    183.38 (ACRES)        .29 (SQUARE MILES)

 HYDRAULIC LENGTH=   4766.08 (FEET)
 TIME CONCENTRATION=      1.03 (HOURS)
 RAINFALL=      7.20 (INCHES)
 VOLUME OF RUNOFF=      3.91 (INCHES)
 PEAK DISCHARGE=    355.84 (CFS)

 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
 IN ACCORDANCE WITH THE SCS METHOD OF ESTIMATING VOLUME OF
 RUNOFF THE TIME OF CONCENTRATION AND HYDRAULIC LENGTH ARE
 VALID FOR WATERSHEDS OF LESS THAN 2000 ACRES (SCS-TP-149)
 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!


  **WOULD YOU LIKE A MAP OF PRESENT CONDITIONS(Y/N)**
y
  ........................MAP MODULE..........................

  **MAP REQUIRES A TERMINAL WITH MININUM   80 CHARACTER WIDTH**
  **ENTER OUTPUT UNIT(END WITH DECIMAL)**
 6.
  **DO YOU WANT A MAP OF MONT. CO AER. PHOTO LAND COVER (Y/N)**
 y
  **DO YOU WANT DEFAULT OR NEW MAP SYMBOLS (D/N)?**
 d
```

```
                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111111111111111111111111100000000000000000000000
                222222222211111111111100000000000099999999999988888888888
                443322110055443322110055443322110055443322110055443322110
                505050505050505050505050505050505050505050505050505050505

                000000000000000000000000000000000000000000000000000000000
                223333333333444444444455555555556666666666777777777788888
                890123456789012345678901234567890123456789012345678901234
390415  40          ###
390410  41        ###FJJ##
390405  42      ##DAAJJJJJ#
390400  43      #GGJJJJJJ#
390355  44       #GAJJJJJ#
390350  45       #GAJJJJJ#
390345  46        #GLLLL#
390340  47         ##L##
390335  48           #
390330  49       #########################################################
390325  50       #                                                       #
390320  51       #              LAND COVER IMPACT STUDY                  #
390315  52       #              MONT. CO AER. PHOTO LAND COVER           #
390310  53       #                                                       #
390305  54       # SYM CLASS                               ACRES       % #
390300  55       # ===================================================== #
390255  56       #  A  URBAN USAGE                         18.34   10.00 #
390250  57       #  D  GRASS                                4.58    2.50 #
390245  58       #  F  DECIDUOUS FORESTS                    4.58    2.50 #
390240  59       #  G  IDLE LANDS                          22.92   12.50 #
390235  60       #  J  RURAL RESIDENTIAL                  110.03   60.00 #
390230  61       #  L  SINGLE FAMILY                       22.92   12.50 #
390225  62       #     TOTAL                              183.38  100.00 #
390220  63       #                                                       #
390215  64       #########################################################
                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111111111111111111111111100000000000000000000000
                222222222211111111111100000000000099999999999988888888888
                443322110055443322110055443322110055443322110055443322110
                505050505050505050505050505050505050505050505050505050505

                000000000000000000000000000000000000000000000000000000000
                223333333333444444444455555555556666666666777777777788888
                890123456789012345678901234567890123456789012345678901234

 **DO YOU WANT A MAP OF MONTGOMERY COUNTY HYDRO SOIL     (Y/N)**
n
 **DO YOU WANT A MAP OF MONTGOMERY COUNTY % SLOPE        (Y/N)**
n
 .........................END MAP MODULE..........................

 ============================ANALYSIS COMPLETE=====================

 ######################HYDROLOGIC ANALYSIS PROGRAM###############
 INPUT:
 B=BOUNDARY    H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
 U=UPDATE      S=STOP

u
 ==============================UPDATE MODULE======================

 **ARE THERE ANY CHANGES IN THE 390730 771500 TOPO(Y/N)**
y
 1=LAND COVER 2=SOILS 3=SLOPE
 ROWCOL123 (TERMINATE WITH "END")
 ---------
  41 33k
  42 30k
  42 31k
  42 32k
  43 29k
  43 30k
end

          ===WATERSHED ANALYSIS (SCS-TR-55)===

 IDENTIFICATION=LAND COVER IMPACT STUDY
 RAINFALL(INCHES)=        7.20
 DRAINAGE AREA(ACRES)=    183.38        .29 (SQUARE MILES)
 HYDRAULIC LENGTH(FEET)=   4766.08

 QUANTITY                             PRESENT    PROPOSED
 CURVE NUMBER                           71.17       74.15
 AVERAGE PERCENT SLOPE                   5.34        5.34
 TIME OF CONCENTRATION(HOURS)            1.03         .95
 VOLUME OF RUNOFF                        3.91        4.23
 PEAK DISCHARGE(CFS)                   355.84      408.92
```

```
      ===CHANGE IN RUNOFF                  .32 (INCHES)        8.24 %=:
      ===CHANGE IN PEAK DISCHARGE        53.08  (CFS)         14.92 %=:

   !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
   IN ACCORDANCE WITH THE SCS METHOD OF ESTIMATING VOLUME OF
   RUNOFF THE TIME OF CONCENTRATION AND HYDRAULIC LENGTH ARE
   VALID FOR WATERSHEDS OF LESS THAN 2000 ACRES (SCS-TP-149)
   !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

 **WOULD YOU LIKE A MAP OF PROPOSED CONDITIONS(Y/N)**
y
 ..........................MAP MODULE...........................

 **DO YOU WANT A MAP OF MONT. CO AER. PHOTO LAND COVER (Y/N)**
y
 **DO YOU WANT DEFAULT OR NEW MAP SYMBOLS (D/N)?**
d
                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111111111111111111111111100000000000000000000000
                222222222211111111111100000000000099999999999988888888888
                443322110055443322110055443322110055443322110055443322110
                505050505050505050505050505050505050505050505050505050505

                000000000000000000000000000000000000000000000000000000000
                223333333333444444444455555555556666666666777777777788888
                890123456789012345678901234567890123456789012345678901234
390415  40          ###
390410  41        ###KJJ##
390405  42      ##KKKJJJJJ#
390400  43      #KKJJJJJJ#
390355  44       #GAJJJJJ#
390350  45       #GAJJJJJ#
390345  46        #GLLLL#
390340  47         ##L##
390335  48           #
390330  49
390325  50
390320  51       #########################################################
390315  52       #                                                       #
390310  53       #              LAND COVER IMPACT STUDY                  #
390305  54       #              MONT. CO AER. PHOTO LAND COVER           #
390300  55       #                                                       #
390255  56       # SYM CLASS                               ACRES       % #
390250  57       # ===================================================== #
390245  58       #  A  URBAN USAGE                          9.17    5.00 #
390240  59       #  G  IDLE LANDS                          13.75    7.50 #
390235  60       #  J  RURAL RESIDENTIAL                  110.03   60.00 #
390230  61       #  K  INDUSTRIAL/COMMERCIAL               27.51   15.00 #
390225  62       #  L  SINGLE FAMILY                       22.92   12.50 #
390220  63       #     TOTAL                              183.38  100.00 #
390215  64       #                                                       #
390210  65       #########################################################
                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111111111111111111111111100000000000000000000000
                222222222211111111111100000000000099999999999988888888888
                443322110055443322110055443322110055443322110055443322110
                505050505050505050505050505050505050505050505050505050505

                000000000000000000000000000000000000000000000000000000000
                223333333333444444444455555555556666666666777777777788888
                890123456789012345678901234567890123456789012345678901234
 **DO YOU WANT A MAP OF MONTGOMERY COUNTY HYDRO SOIL     (Y/N)**
n
 **DO YOU WANT A MAP OF MONTGOMERY COUNTY % SLOPE        (Y/N)**
n
 .........................END MAP MODULE..........................

 ============================UPDATE COMPLETE========================

 ######################HYDROLOGIC ANALYSIS PROGRAM###################
 INPUT:
 B=BOUNDARY    H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
 U=UPDATE      S=STOP

s
NORMAL EXIT.  EXECUTION TIME:        4323 MILLISECONDS.
```

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